Making do with less (data): Compressed Sensing in MRI

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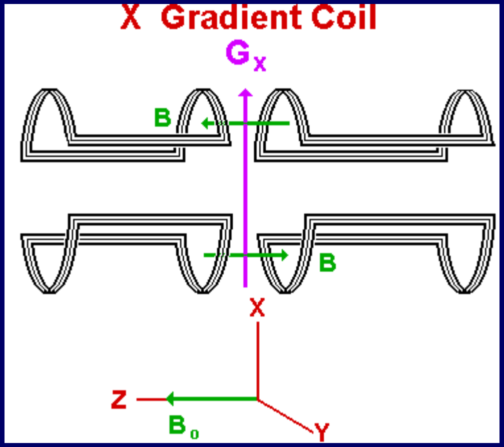
Outline

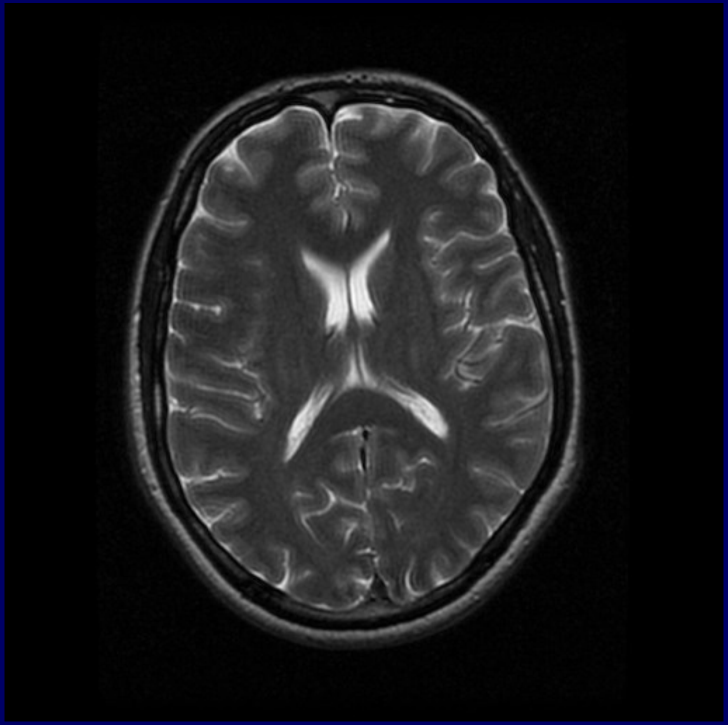
Data acquisition in MRI
Undersampling
Compressed Sensing in MRI
Practical issues
Applications

Mike Davies, Engineering

Spatially localised NMR = MRI

Lauterbur 1973 and Mansfield 1973





MRI acquisition

Excite

Evolve

Acquire

MRI acquisition

repeat

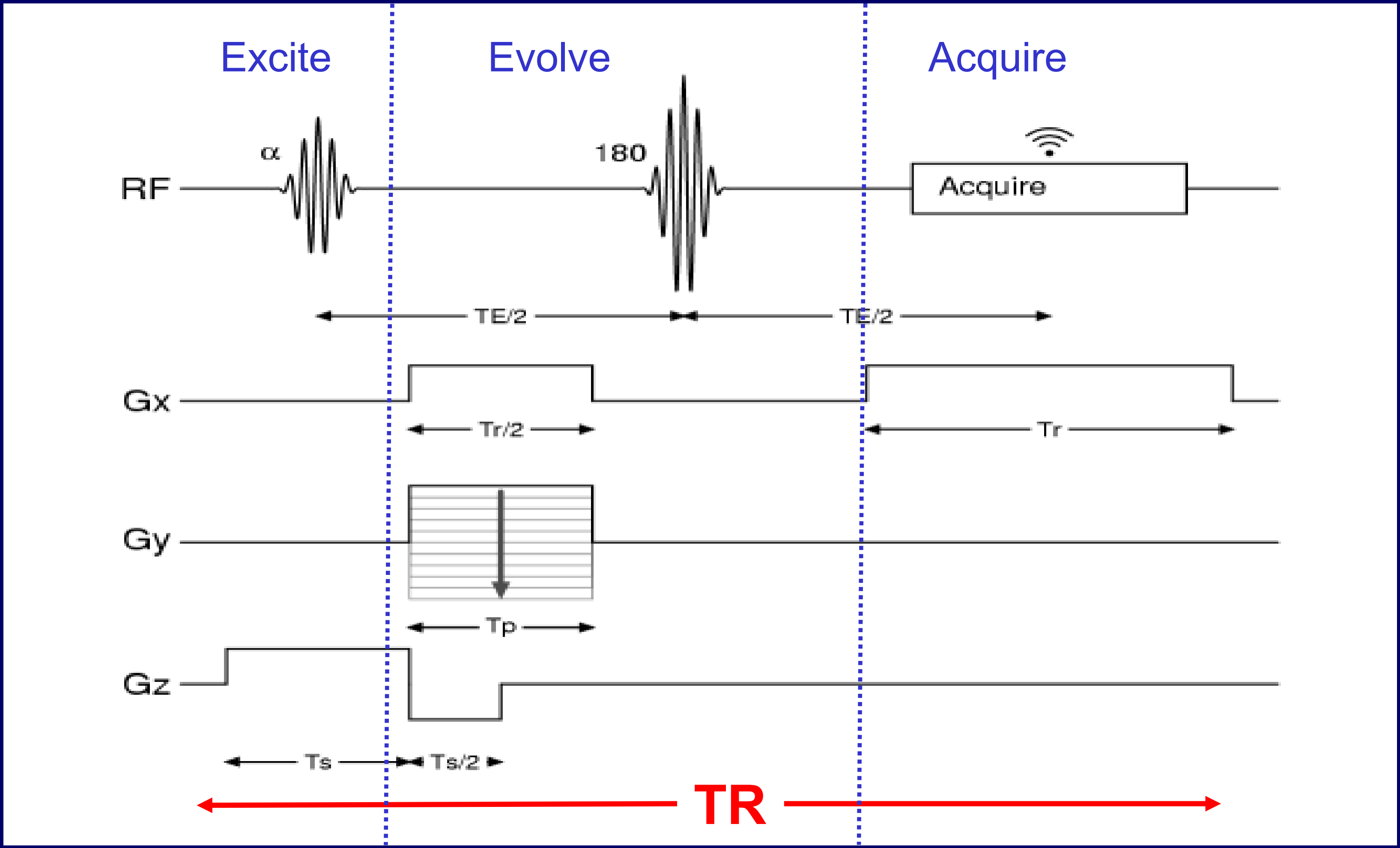
Excite

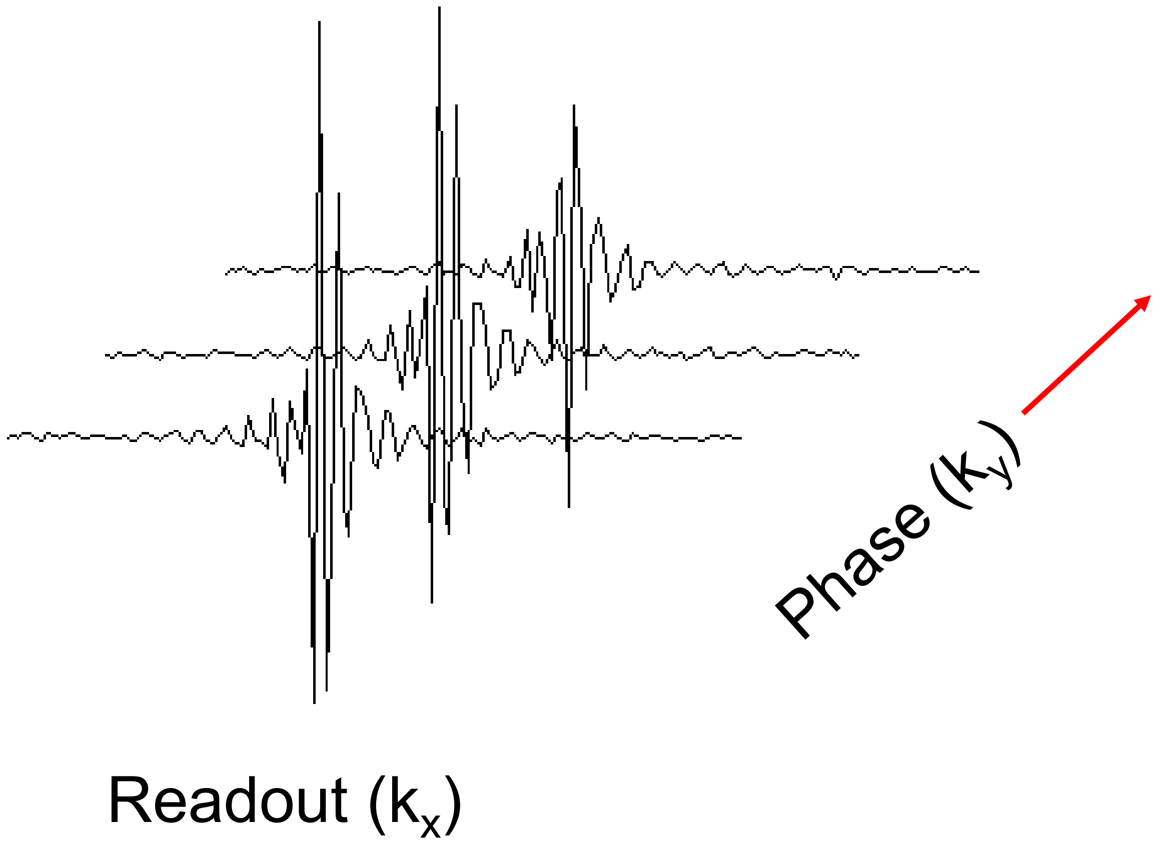
Evolve

Acquire

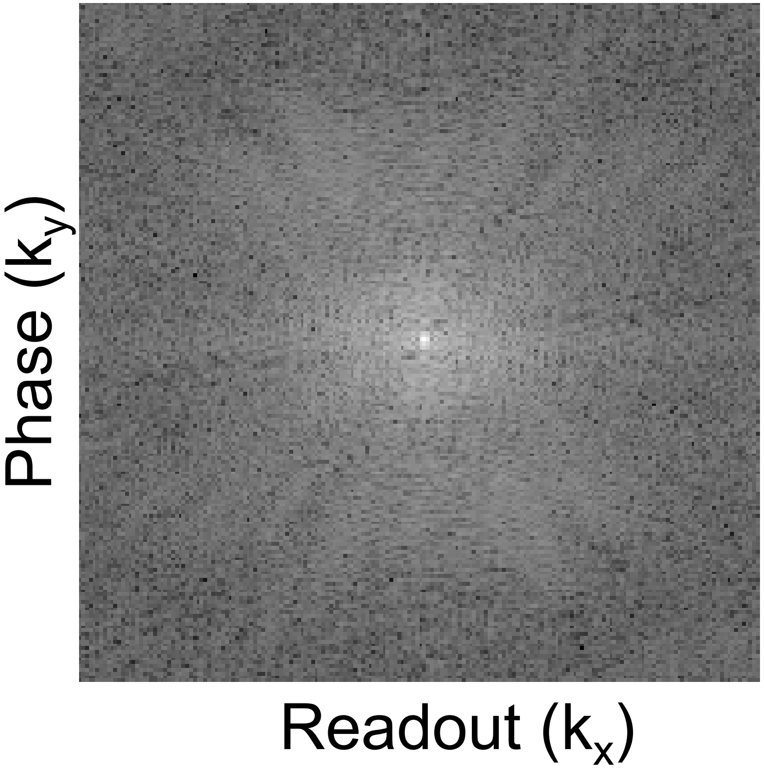
until spatially encoded

MRI acquisition

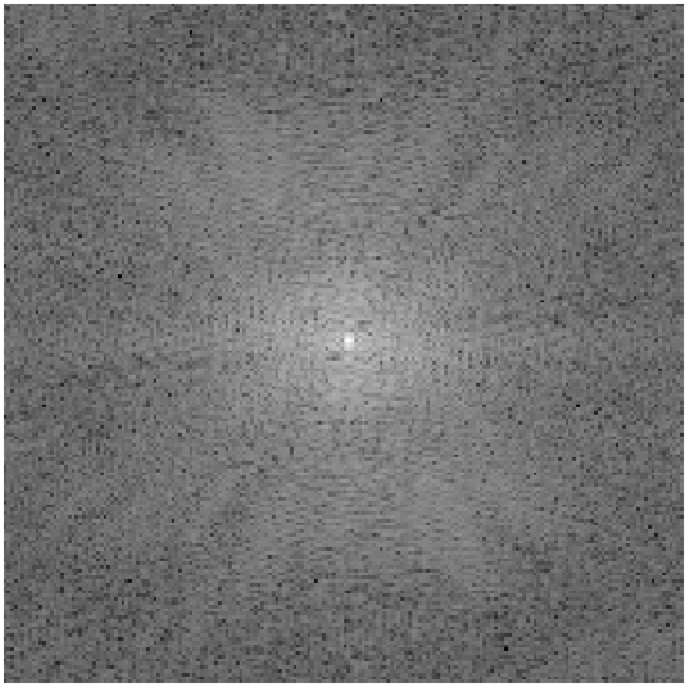




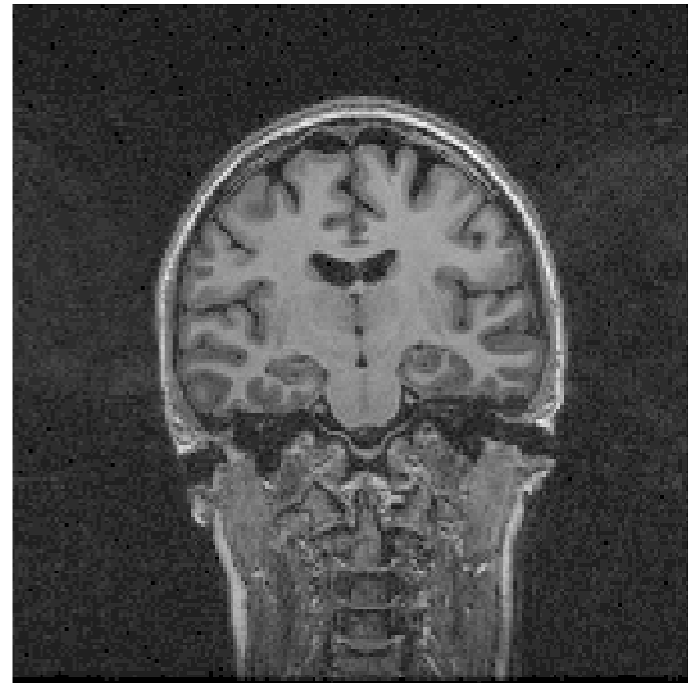
Acquired signals



k-space

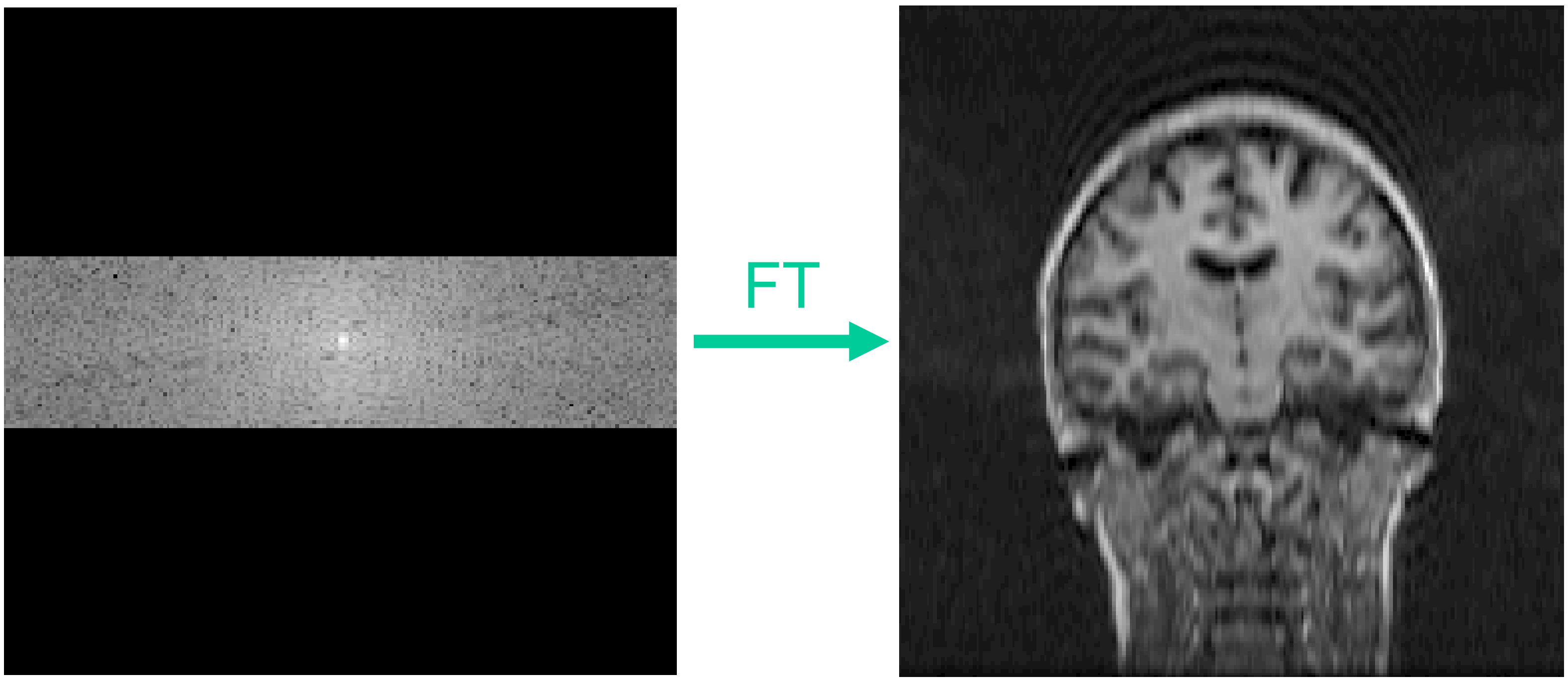


FT

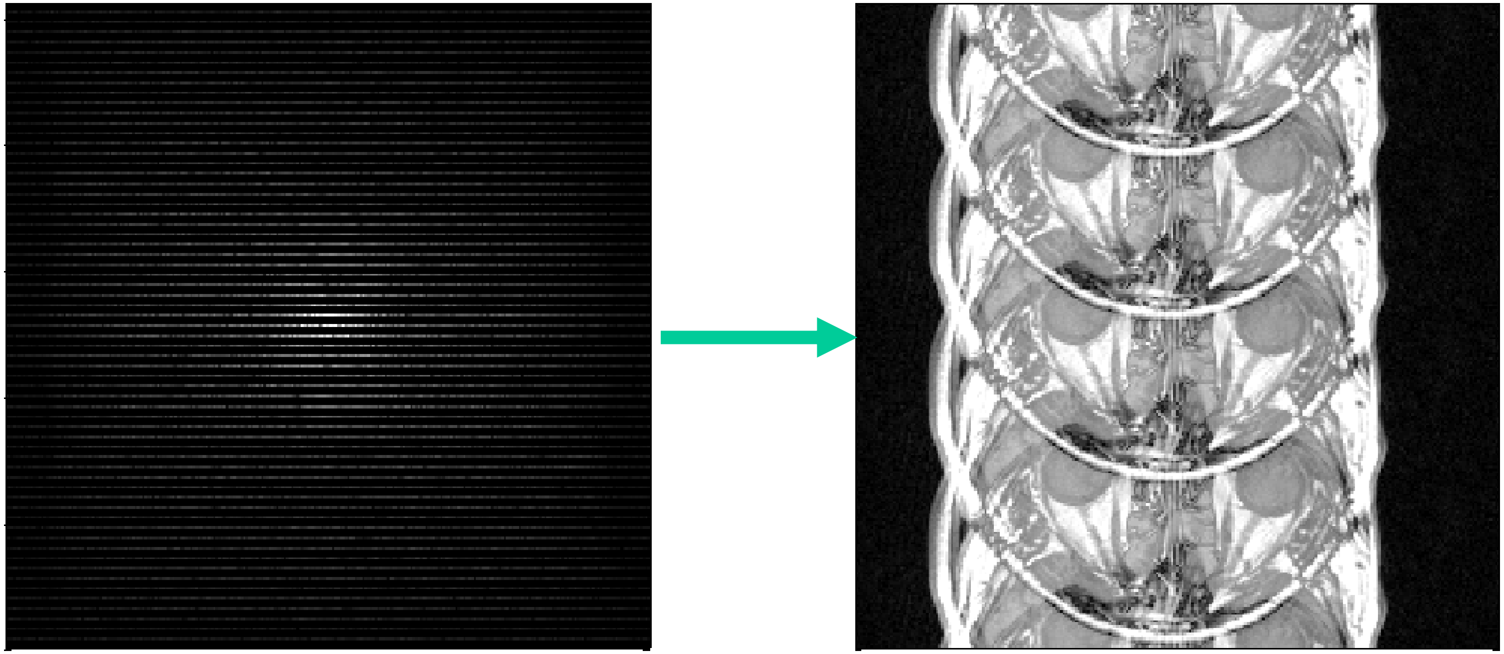


k-space

image space



k-space image space



Is there a better way?

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Most images are ‘sparse’

Data compression (JPEG, MPEG)

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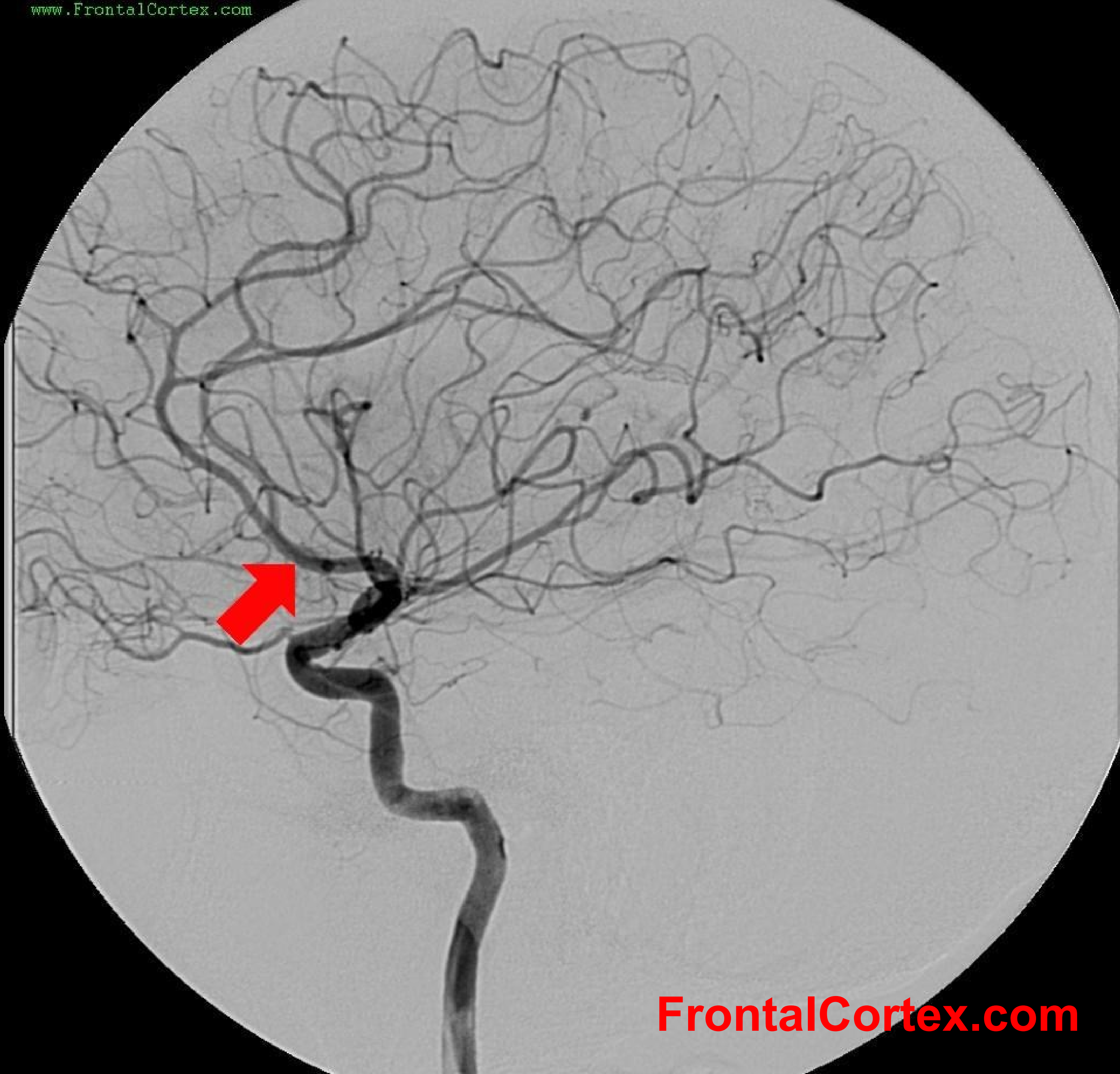
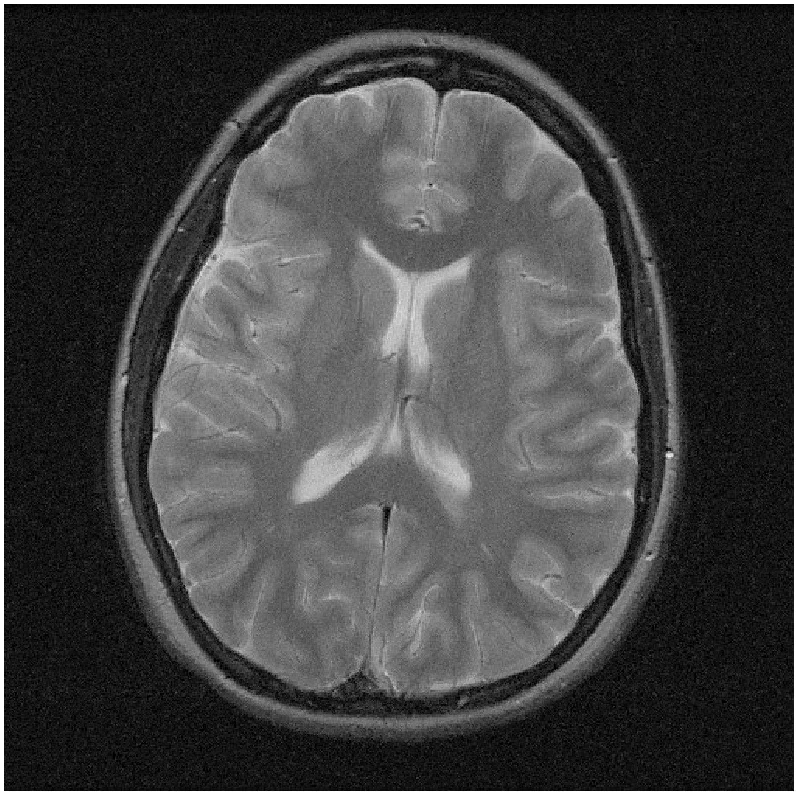
Data compression (JPEG, MPEG)

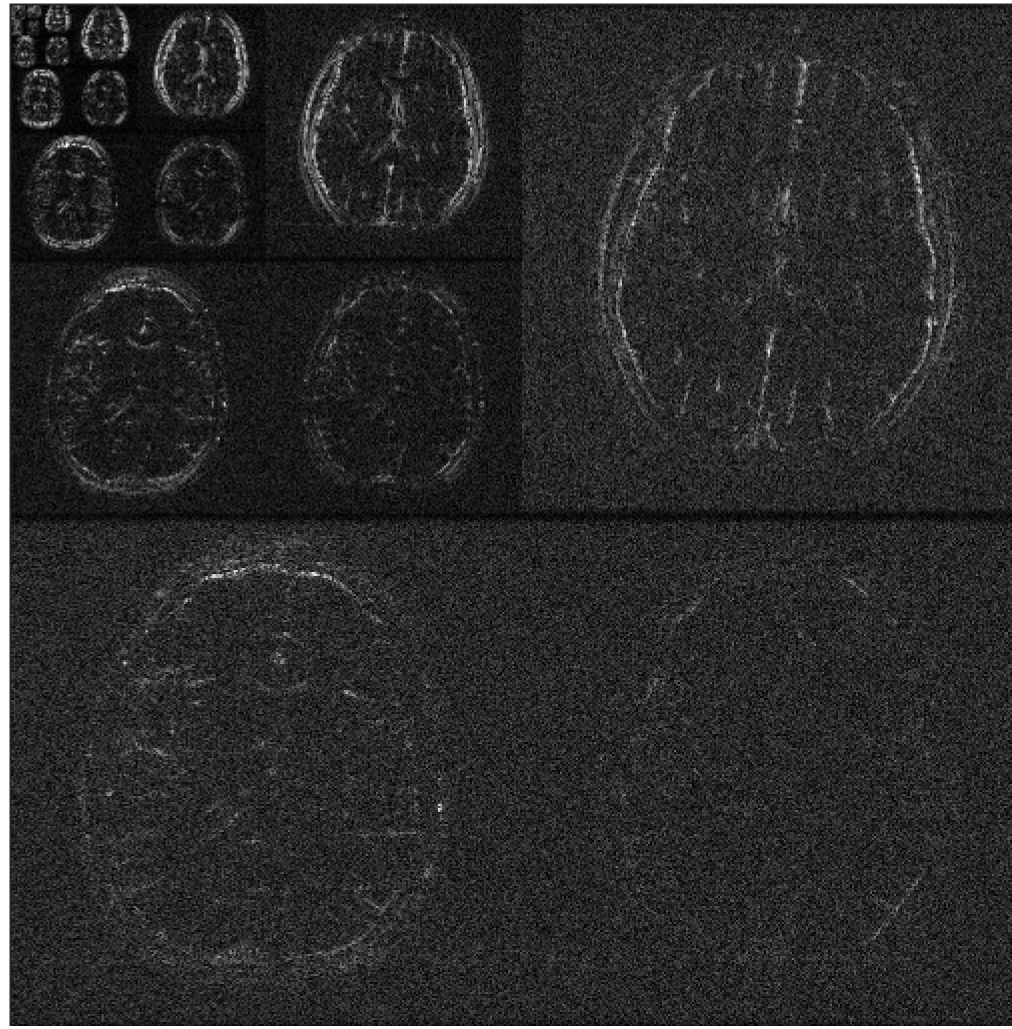
If you don’t need the data,
why collect it?



T2w brain image



Wavelet transform



http://www.eecs.berkeley.edu/~mlustig/CS.html

Compressed Sensing

Candes 2006, Donoho 2006
IEEE Trans Inf Theory

Lustig *Magn Reson Med* 2007

Compressed Sensing

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Sparsity

Randomly undersampled data

Nonlinear reconstruction

http://www.eecs.berkeley.edu/~mlustig/

X

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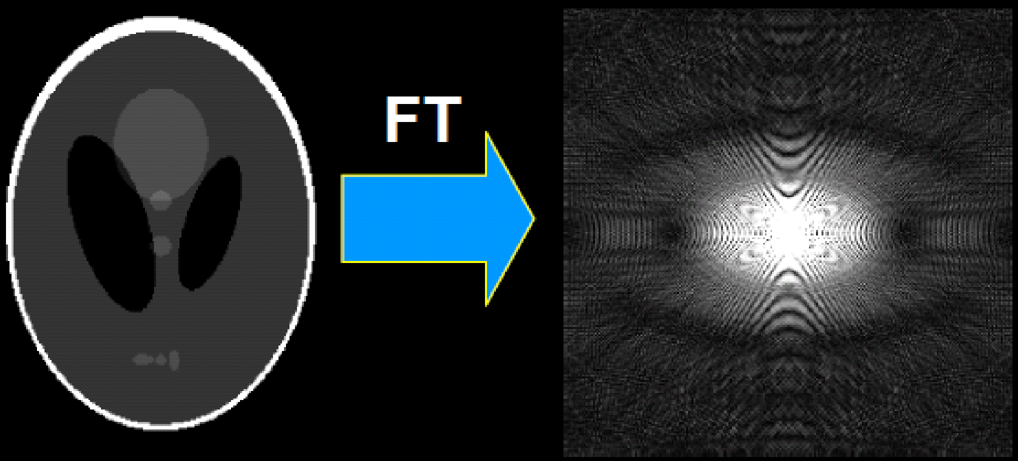
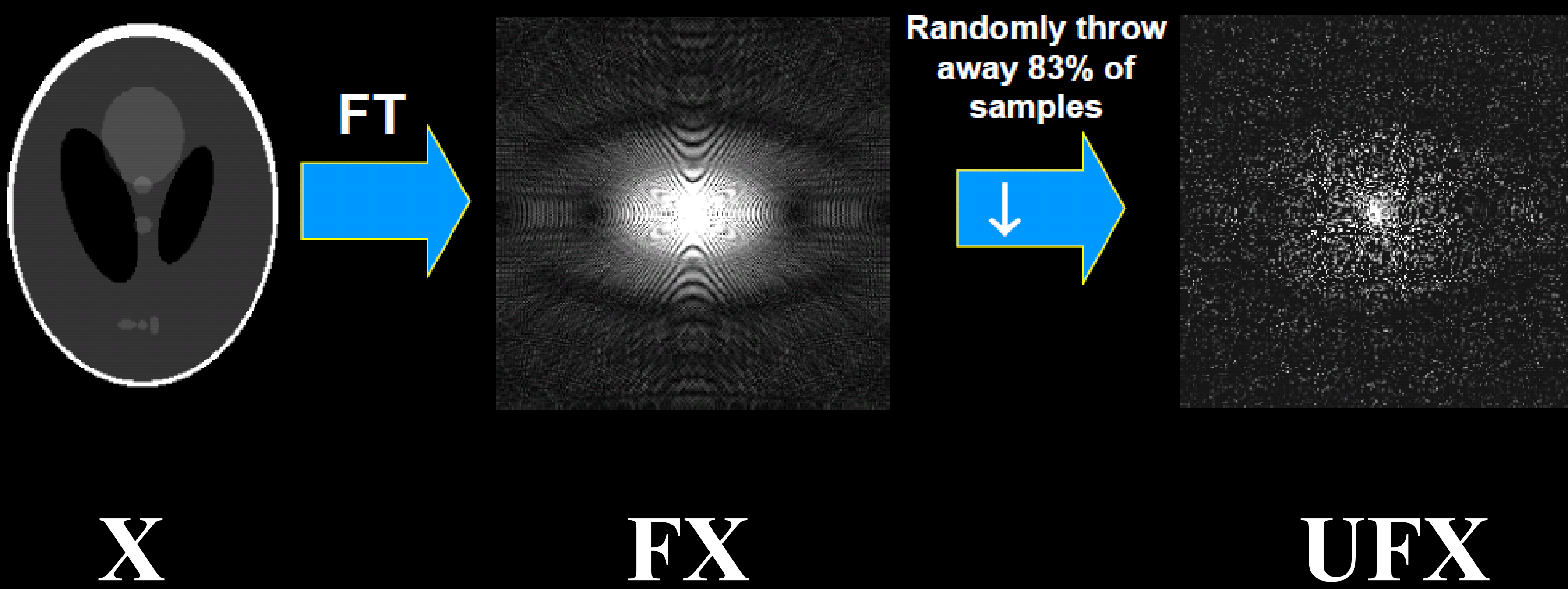
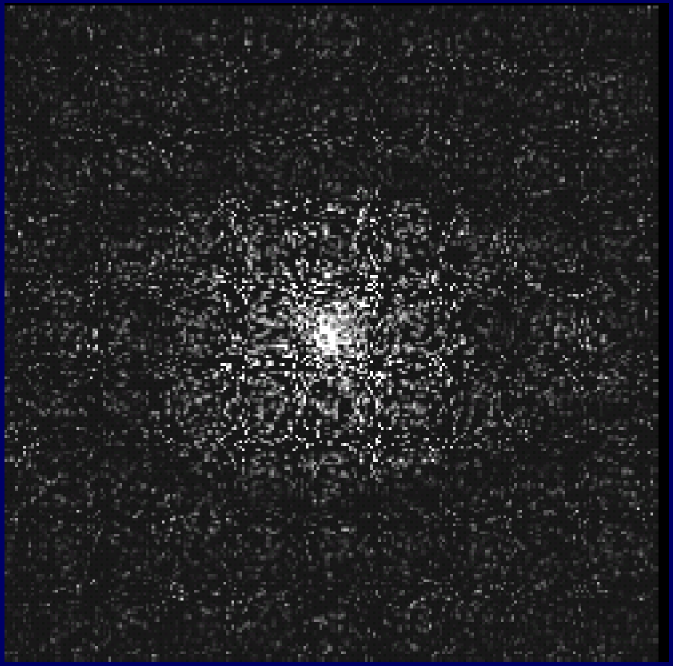


X **FX**

http://www.eecs.berkeley.edu/~mlustig/

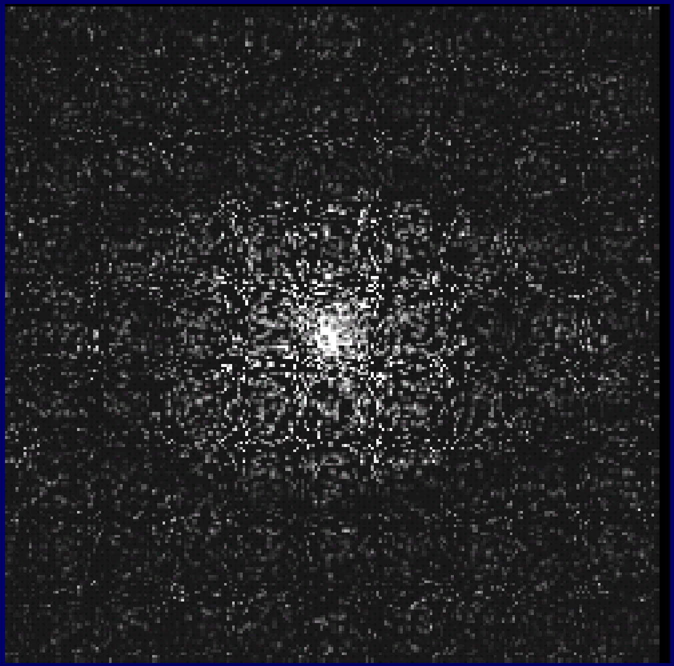


$$Y = U F X$$



$$Y = U F X$$

$$\|Y - U F X\|^2 < \varepsilon$$ (Least Squares)



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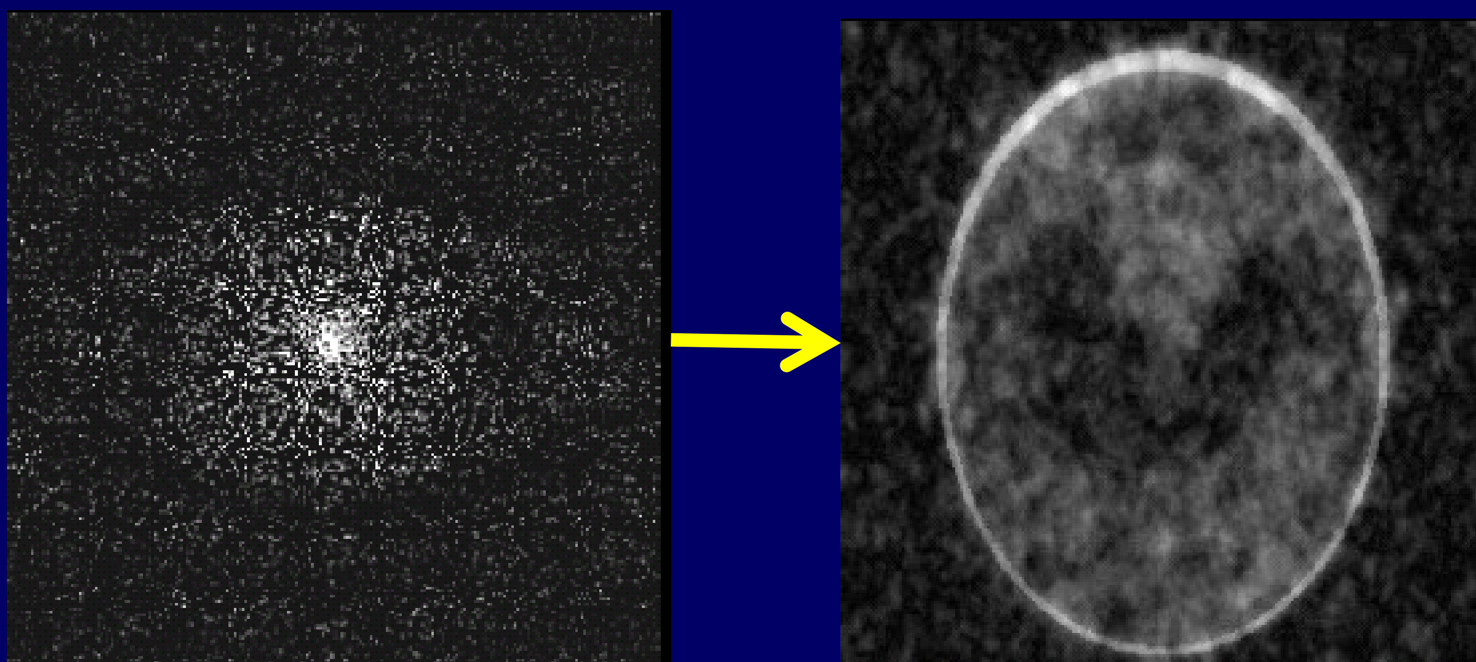
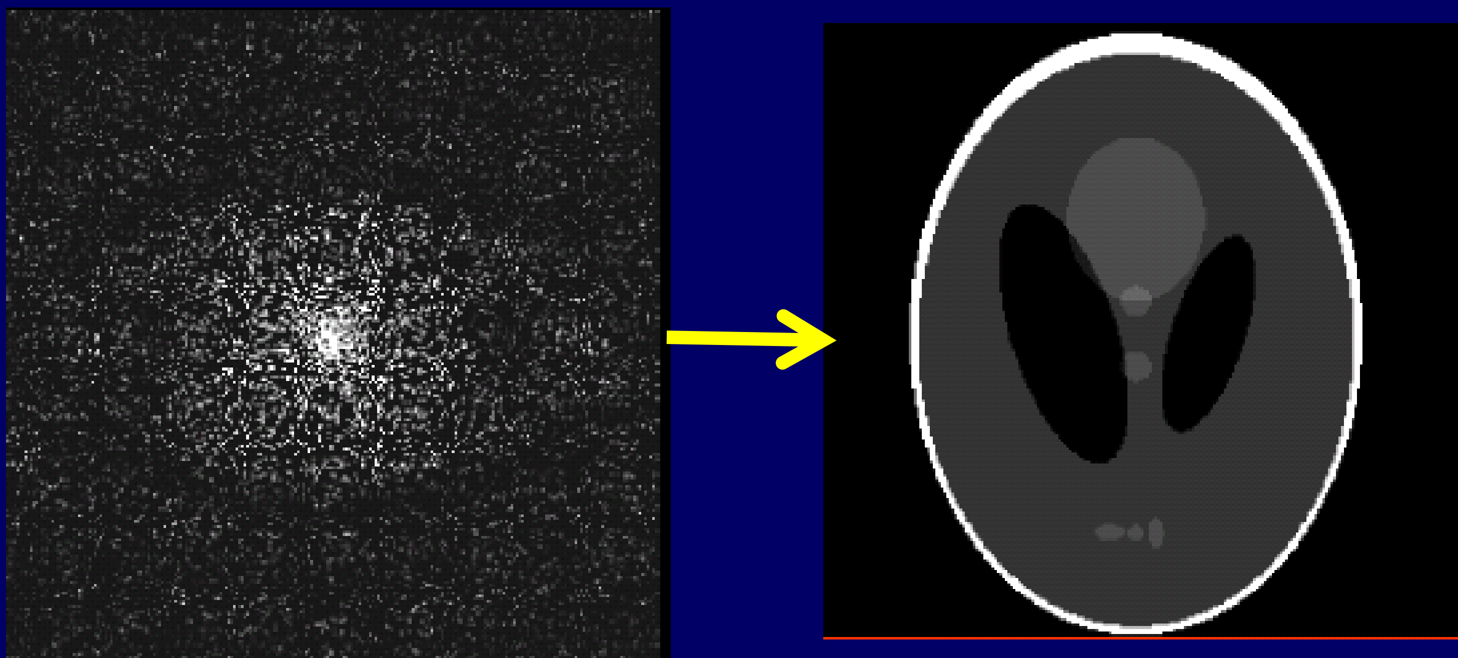


Compressed Sensing

Minimise $\|Q\ X\|_1$ **(sparsity)**

subject to…

$\|Y - U\ F\ X\|^2 < \varepsilon$ **(data consistency)**



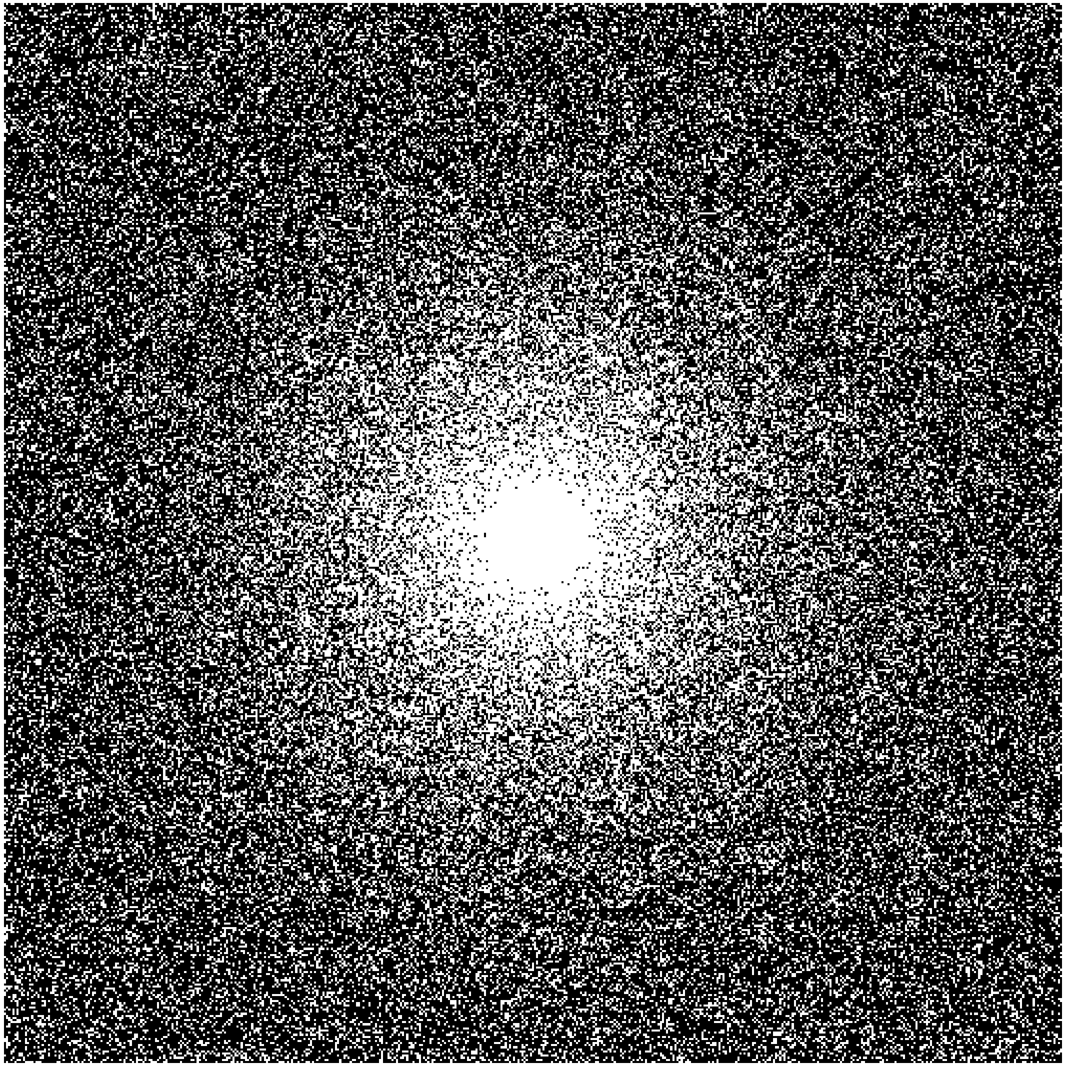
"…the results are surprising" (Candes 2006)

Minimise the objective function…

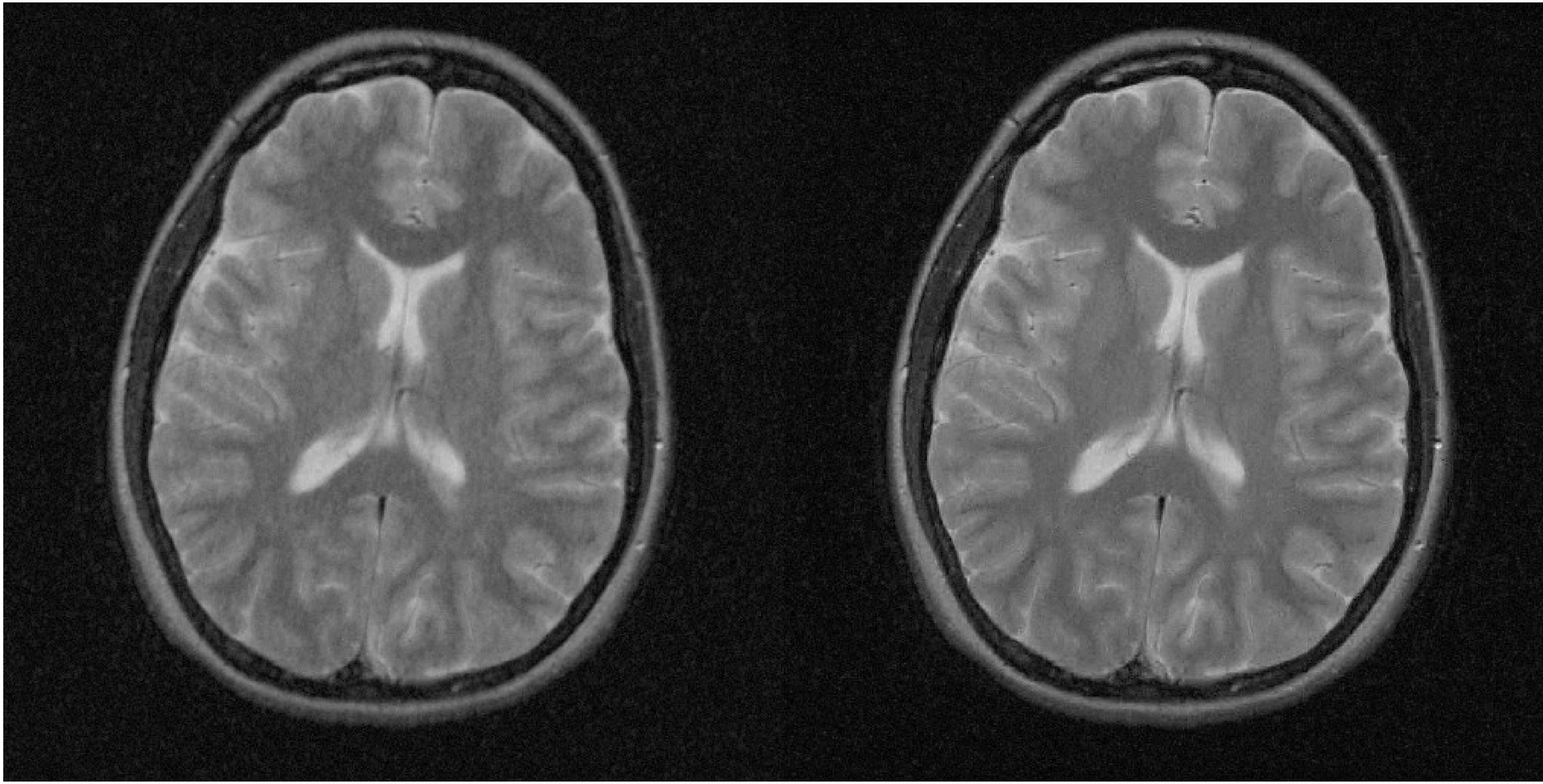
$$\{\ \|\mathbf{W}\ \mathbf{X}\|_1 + \lambda\ \|\mathbf{Y}\ -\ \mathbf{U}\ \mathbf{F}\ \mathbf{X}\|^2\}$$

Iterative solution

3 times undersampling mask



Linear recon CS recon



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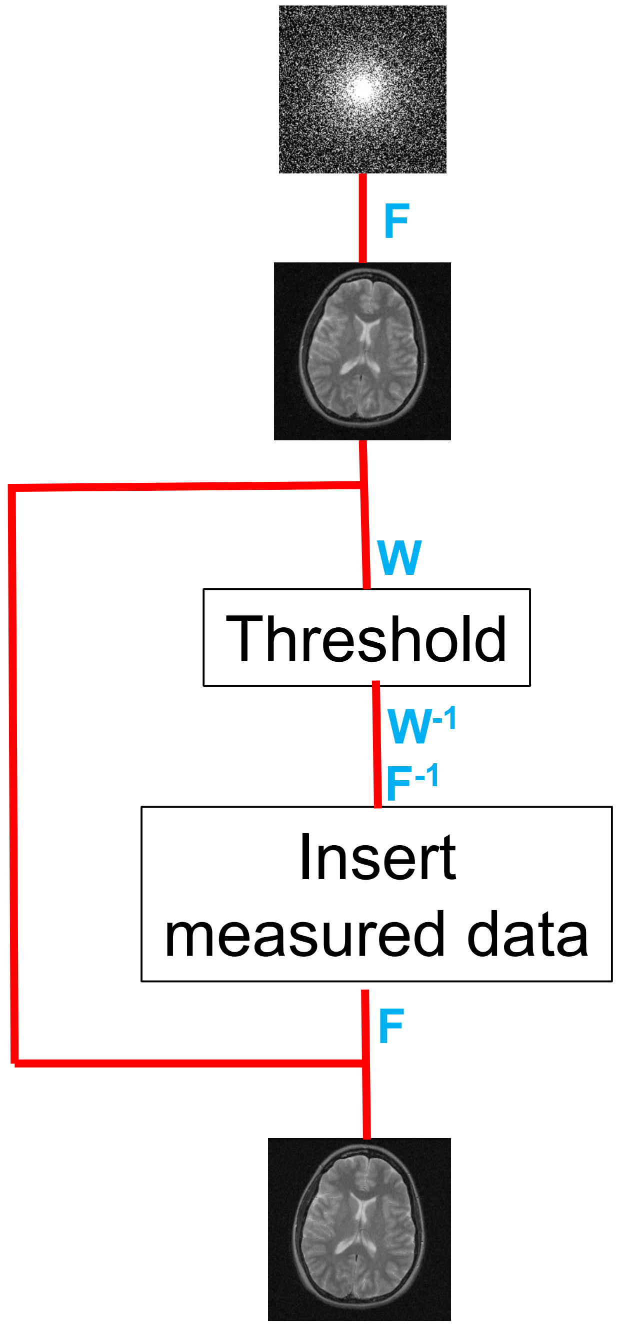


Enforce sparsity in W-domain

Data consistency in k-space

But…

We can’t undersample in k_x

1D undersampling doesn’t work well

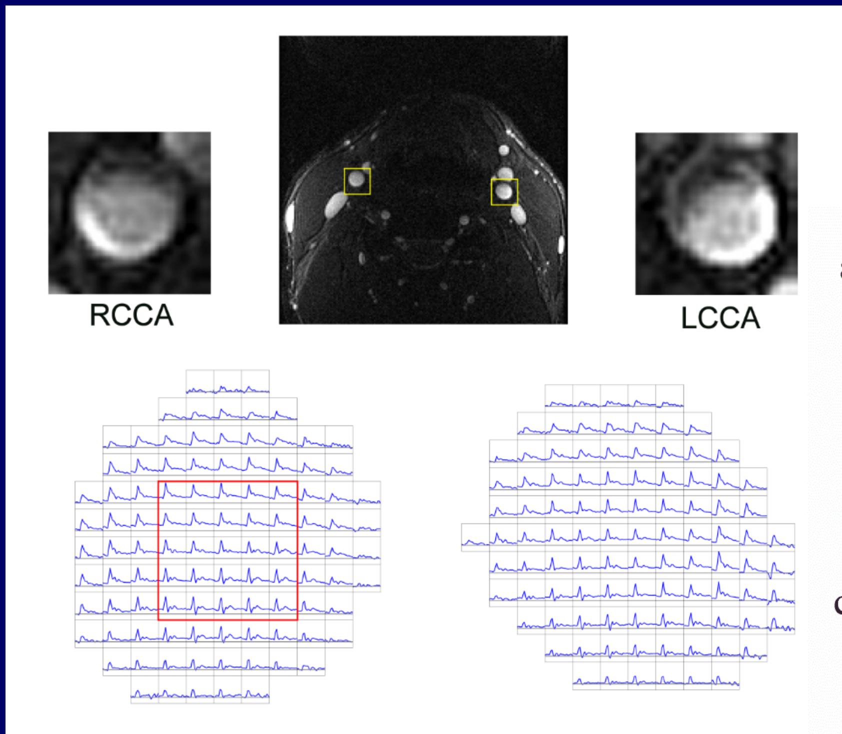
2D undersampling pattern is critical

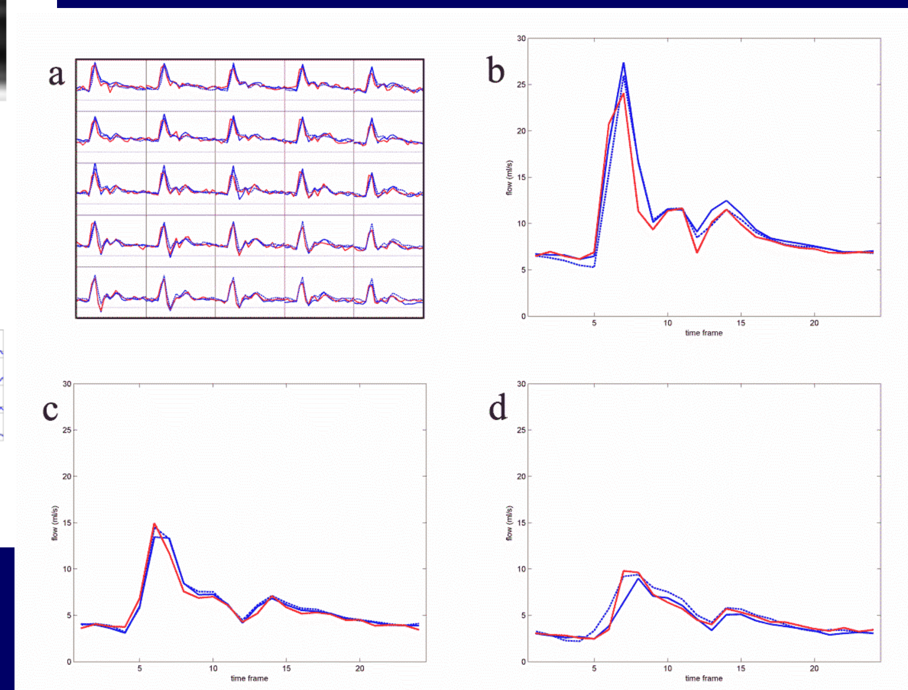
Applications

Need to undersample
in 2 or more dimensions

Standard 2D Brain	-
3D brain	+
Multiparameter 2D brain	+
Cardiac	+
Blood flow	+

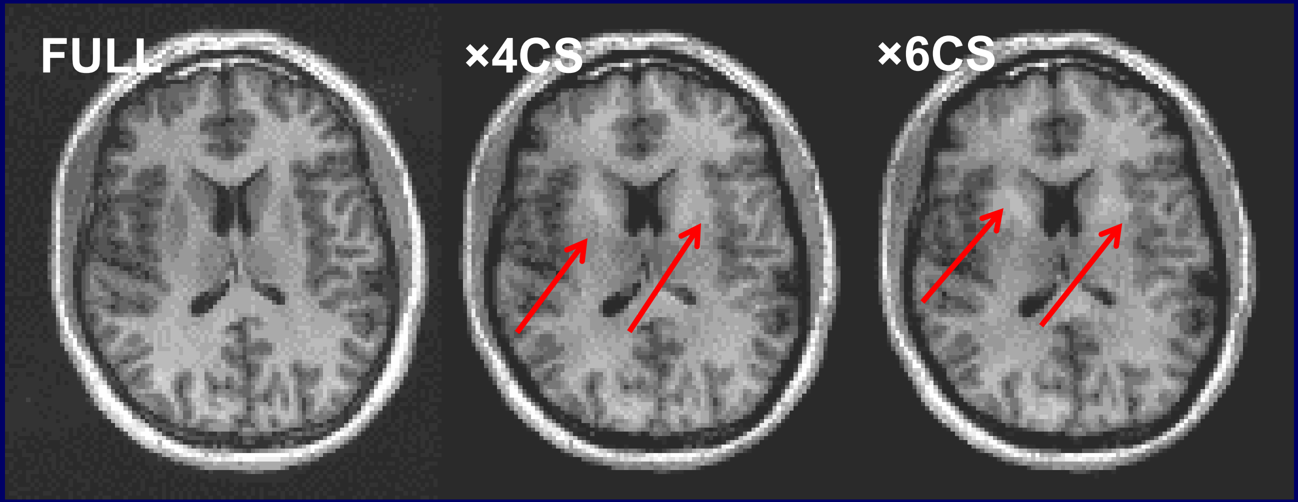
Carotid blood flow

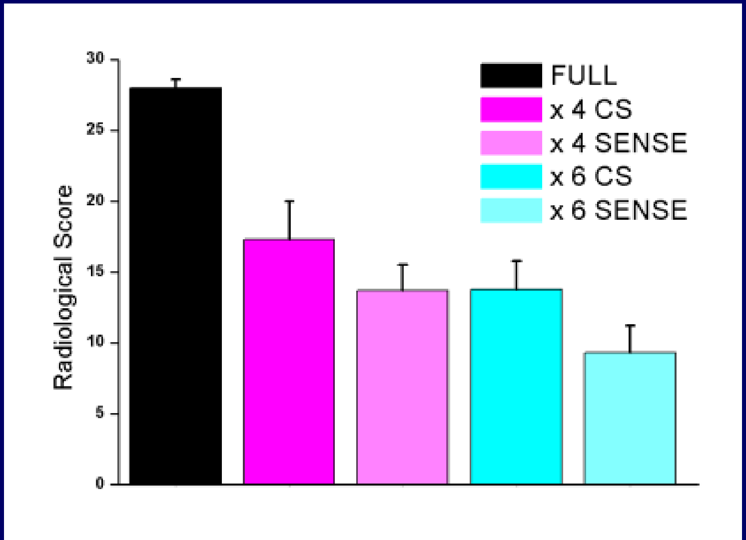




Tao et al, *Magn Reson Imag* 2013

UNDERSAMPLED 3D BRAIN IMAGES





ISMRM 2015, #2497

Current work

Quantitative parameter mapping

Multichannel data

Non-equilibrium sequences

Mike Davies
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